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ABSTRACT

The intellectual development of students as defined by Piagetian theory is discussed with the implications that the theory and recent research results may have for teaching science. Recommended is conducting small, carefully planned investigations that will lead to a better understanding of: (1) what concepts cause problems and why; (2) what strategies will help in teaching these concepts; (3) what thinking students use as they approach typical problems; and (4) how the thinking process can be improved. Curriculum changes, however, should not be rushed till information of this sort is available. (SL)

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PIAGET APPLIED: SUGGESTIONS FOR INACTION

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By titling my paper, Suggestions for Inaction, I provide ample opportunity for being misunderstood. I really don't want to suggest that we make no attempt to apply Piaget's theory of intellectual development to the teaching of chemistry. I merely want to caution against certain kinds of action and argue for others.

Let me begin by making a point that seemed unnecessary until now. That point is that Piaget's theory is not a theory about instruction; i.e., it does not tell us how to go about teaching science or any other subject. Rather, it is a theory of intellectual development; i.e , it tells us how the intellect develops from infancy to adolescence.

This is an important distinction. Piaget's theory may have implications for teaching science but the theory is not one that finds direct application in developing teaching strategies. There are necessary intervening steps.

In essence, Piaget tells us that the intellect develops through certain stages which can be characterized by the reasoning exhibited at various ages. Further, he tells us that the order of this development is invariant; i.e., every individual appears to move from the sensory-motor stage of the infant to the pre-operational stage of the young child to the concrete operational stage of the elementary school student to the formal operational stage of the adolescent. Even though the age at which an individual moves from one stage to the next may vary from culture to culture or from individual to individual,

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the order of that development appears to be invariant.

Once one has examined the reasoning characteristic of each stage, it is evident that there are some things that can be understood by a person at the formal operational level that cannot be understood by a person at the concrete operational level and so on down the scale. As a matter of fact, an analysis of what we teach in chemistry suggests that a large portion of these concepts and principles can be understood only through formal operational thought. This, coupled with the large body of information suggesting that 50% of college freshmen do not use formal operational thought, says that we have a problem. (McKinnon and Renner, 1971; Lovell, 1961; Elkind, 1962; Tower and Wheatley, 1971; Jackson, 1965; Tomlinson-Keasey, 1972) It does not say what we should do about the problem.

What concerns me at this point is that we may be trying to move too quickly from an awareness of Piaget's theory to a solution based on his work. The reason for such anxious movement is clear enough. The problem isn't new. We have known for a long time that many students don't understand chemistry. We have even known that they have difficulty with proportional reasoning, combinatorial reasoning, thinking in terms of possibilities rather than observed reality, controlling variables in an experiment, and reasoning with abstract entities such as atoms, molecules, and ideal gases. The only thing new is our recognition of the strong correlation between the reasoning that our students find difficult and the reasoning that Piaget describes as formal operational thought. We are almost impelled to the inference that many students have trouble with chemistry because they have not developed intellectually to the level of formal operations. (Herron, 1975, 1976)

I happen to believe that we have drawn the correct inference but it is a long way from that inference to an understanding of what we can or should

do about it. It is in the arena of "where do we go from here" that I want to make some suggestions for inaction.

If one accepts that as many as 50% of college freshmen do not consistently use formal thought and that much of what we hope to teach in chemistry requires formal thought, one action might be to administer a test of intellectual development as a screening test for entering students. Whether those caught by the screen are placed in remedial courses or denied admission to chemistry altogether would vary from one school to another. This is the first area in which I would counsel inaction.

Although it is probably true that lack of intellectual development is one of the reasons that students have difficulty in chemistry, it would be naive to assume that it is the only reason. Students have difficulty because they have not developed basic math skills, because they cannot read, because they have poor study habits, and because they aren't motivated. A perfect test of intellectual development would not tap these sources of difficulty. Placement decisions made on the basis of such a test could be worse than decisions based on scores from tests such as the SAT or the Toledo Exam which probably tap some aspects of intellectual development as well as other factors that I have mentioned.

<u>If</u> we had a test of intellectual development which could be administered easily and <u>if</u> that test were highly reliable and valid, it <u>might</u> contribute something to what we can learn from tests that are already being used but that has yet to be established.

When a group at the University of Nebraska (Albanese, et al., 1976) added items that they considered to be measures of intellectual development to a test used for placement purposes, the Piaget items did not contribute significantly to the predictive validity of the test.

There are several possible explanations for this result, some of which I have discussed in an earlier paper (Herron, 1976). I will not go into them here.

Before leaving the Albanese study I would like to speak to one question raised by that study and that is just how much of the variance in student achievement can be explained by intellectual development as measured by a test based on Piaget's theory. Albanese, et al. found that their Piagetian scales could account for only about 6% of the variance in course grades. (Ibid, p. 572) At the other extreme, Hammond's data (Hammond, 1974) suggest that a battery of individually administered Piagetian tasks could account for about 60% of the variance in grades. Most other data that I have seen fall between these extremes.

Sills reports several correlations between his written Piaget test and various measures of achievement. His average correlation is 0.4 and thus accounts for something in the order of 16% of the variance in achievement. (Sills, 1977) Bauman reports substantial correlations between Piagetian stage and grade but does not provide a numerical value for the correlation. (Bauman, 1976) In a study just completed by one of my graduate students, we found correlations between the Longeot test and first semester grades in two high school chemistry courses of 0.48 and 0.58. (Cantu and Herron, 1977) This corresponds to about 30% of the variance in achievement.

It seems clear that the amount of variance in course grade that can be attributed to intellectual development as measured by a Piaget test will depend on the type of Piaget test used, the nature of the course taught, and the instructor in the course. As an average, we can probably assume that a good Piaget test will account for somewhere between 20 and 40% of the variance in grades. This is important but not sufficient for sound placement decisions.

Most of us are not content with learning which students operate at the concrete operational level and which students operate at the formal level. We are, after all, chemistry teachers and we want to teach chemistry. If our students use concrete operational thought, we want to teach them chemistry just the same. If we can do that without their developing formal operational thought, we are probably content to do so; if we cannot, we want to make them formal operational.

Several people, including the author, teach courses which they hope will help poor chemistry students become good chemistry students. This is not a new phenomenon. Many junior colleges have been trying to do this for decades and most large universities have been making some effort in this area in the last 5-10 years. What is new is that more and more people seem to be looking to Piaget for guidance. I am encouraged by this but hope that we will not be naive about it. Nobody--including Piaget--knows how to take college students who are not using formal operational thought and get them to the point that they are using formal operational thought in a period of a year or less. Nobody knows how to teach students who are at the concrete operational level, concepts and principles that are normally understood only by students who use formal operational thought.

I don't want to be too pessimistic. There are people who are doing things that <u>appear</u> to help. You have heard from several of these people at this conference. Let me mention a few others.

Arnold Arons has been teaching a physical science course for elementary education majors at the University of Washington for a number of years now. He began teaching the course before he heard of Piaget but he was clearly concerned about the same problems of intellectual development that we associate with formal operational thought and he recently discussed his course in terms

of Piaget's theory. (Arons, 1976) Arnold believes that he has made significant progress with his students and I agree. However, he doesn't help them all--in spite of his and their best efforts--and the progress that is made does not come quickly or painlessly. Furthermore, his teaching style requires a teacher-student ratio that would frighten the beleagered department chairman struggling with an anemic budget.

Aron's course has been used at other institutions with about the same results that he has obtained. Van Neie teaches such a course at Purdue and Dick Dilling has used a similar course at Grace College with encouraging results. (Dilling, 1977)

Many of you have probably heard of the ADAPT Project at the University of Nebraska. In that program, a group of entering students were invited to participate in a special program developed to enhance their intellectual development. Evaluation of a complex program such as ADAPT is difficult but the data collected suggest that the initial effort produced some improvement even though it was not spectacular. (ADAPT, 1976)

Robert Bauman at the University of Alabama in Birmingham has reported on work that he has done in physics that he finds encouraging. (Bauman, undated)

Back in the '60's Robert Karplus began developing an elementary science program, SCIS, which was influenced by Piaget's ideas concerning intellectual development. A learning cycle of exploration, invention, and discovery was developed as part of that project and appeared to be effective. Karplus and his associates have since advocated the same kind of learning cycle for instruction at more advanced levels. It is this learning cycle that provided the rationale for curricular development at ADAPT and they seem to attribute much of their success to it. I know of no hard evidence that the learning cycle will work miracles but it does provide a place to start.

The basic problem with all of these efforts is that they only suggest a place to start. They do not provide enough information about the variables that contribute to success or failure to enable some other person to build a different course for a different group of students in a different instructional setting and have great confidence that it will work.

Let me elaborate. There is a common characteristic of the course taught by Arons, the work of Karplus, the ADAPT Project, and Bauman's work. What is common is that students begin their study of a new idea with some kind of concrete experience which enables them to observe phenomena directly. This is the exploration stage in the Karplus learning cycle. Here a student might be given a battery, a bulb, and a wire with the instruction to see if they can make the bulb light. This exploration may be totally unstructured or may be guided by the teacher but the intent is for the student to observe what happens; to see that the bulb will light under certain arrangements but not others, to observe the brightness of the bulb when connected with other bulbs or batteries in various ways, to observe secondary effects such as wires getting hot, and so forth.

It is not until the student has had an opportunity to see what does happen and to try to "make sense" out of these observations using whatever intellectual skills he might have, that the instruction proceeds to the next stage. In the second stage, the teacher will intervene to "invent" such ideas as "circuit", "complete circuit", "broken circuit", "parallel circuit", and "series circuit". The invention stage might be described as placing labels on the phenomena that the student has already observed. Some students may have come up with the idea of circuit independently; others may have simply observed that the bulb lights in some arrangements and not others but not arrived at the generalization that there must be an unbroken path from

one end of the battery through the filament of the bulb to the other end of the battery. The invention phase provides a generalization that accounts for the observations made during exploration and suggests further, planned observation, which can be used to test the validity of the generalization. This is the phase of instruction that Karplus originally described as "discovery" and the ADAPT people more appropriately label "application".

Karplus, Arons, and others differ in the amount of direction that they provide to students as they proceed through these stages of observing natural phenomena, trying to order those observations in some sensible way, and finally, checking the validity of generalizations through further observation. However, they all begin with concrete experience and they all insist that the student assume a major role in thinking through the experience and doing all that he can to order the information in a sensible way. The teacher may call attention to observations that the student has missed, he may point out inconsistencies between observations and suggested explanations, and he may provide commonly accepted terms such as circuit for phenomena already observed, but he generally does not present his own organization of the observations and ask the student to accept it as established fact.

The kind of teaching strategy that I have just described is consistent with Piaget's notions about how a person develops from one stage of intellectual development to another. Piaget describes this process as equilibration or self-regulation and any introductory treatment of Piaget's theory will provide a discussion of how it takes place.

Since this "learning cycle" is consistent with Piaget's theory of intellectual development and since the efforts of Arons, Karplus and others who use this strategy show some measure of success, I would be willing to argue that this "learning cycle" is a good place to start if we want to encourage

intellectual development. I would not argue that using the learning cycle will necessarily lead to improved thought patterns among students.

In its simplest interpretation, the "learning cycle" strategy seems to be that we begin by providing students with some kind of concrete experience, encourage them to order that experience using whatever intellectual skills they possess, and then try to encourage generalization of the abstracted principles to other areas. It may work providing we attend to other variables at the same time.

Gerald Kulm, mathematics educator at Purdue, recently completed a study that I find interesting and significant. (Kulm, 1977) Kulm teaches a math course for elementary education majors in which many students operate at the concrete operational level. Kulm is very much interested in math labs because they provide concrete experience which might make the abstract ideas of mathematics more meaningful. He hypothesized that laboratory activities would probably be very helpful to concrete operational students who are more dependent on concrete experience for understanding, but that these laboratory experiences might be a waste of time for formal operational students who, supposedly, would be better prepared to handle the abstract presentation given in lecture. Certainly this is a reasonable hypothesis based on our understanding of intellectual development as described by Piaget.

Kulm classified his students as concrete or formal and then assigned half of each group to either a laboratory class or a lecture class.

Kulm's research hypothesis was that the concrete operational students in the laboratory program would score higher on an end-of-unit examination than the concrete operational students in the lecture approach. The opposite was hypothesized for the formal operational students; i.e., that those in the

lecture section would score higher than those in the laboratory section. It didn't turn out that way. As a matter of fact, the results were just the opposite as shown by Table 1. The formal operational students in the laboratory section did better than those in the lecture section and the concrete operational students in the lecture section did better than those in the laboratory section.

Table 1 †

Cell Means and Standard Deviations for Achievement Tests

Treatment Group*	N	Unit II	Unit III	Unit IV	Unit V	Achiev.	Retention
Lecture	41	8.95 (1.43)	8.49 (1.38)	7.76 (2.09)	7.90 (1.94)	39.44 (6.42)	41.74 (6.25)
Concrete	28	9.14 (1.20)	8.53 (1.40)	7.85 (2.35)	7.67 (2.12)	39.46 (5.65)	42.69 (4.95)
Formal	13	8.53 (1.81)	8.38 (1.38)	7.54 (1.45)	8.38 (1.44)	39.38 (8.09)	39.69 (8.27)
Laboratory	48	9.14 (1.03)	9.04 (1.35)	7.08 (2.53)	7.26 (2.78)	39.94 (6.95)	40.91 (9.34)
Concrete	28	8.85 (1.78)	8.64 (1.54)	6.39 (2.89)	7.17 (2.80)	37.57 (7.82)	39.05 (11.28)
Formal	20	9.55 (.60)	9.60 (.75)	8.05 (1.50)	7.35 (2.83)	43.25 (3.58)	43.50 (4.79)

*A score of 3 or less out of 8 on the Formal Reasoning Test was used to classify subjects as concrete.

A summary of the analysis of variance for each achievement test is given in Table 2.

† Table taken from Kulm, 1977.

Table 2 †

Analysis of Variance Summary for Achievement Tests

Source	df	Unit II	Unit III	Unit IV	Unit V	Achieve	Retention
Treatment	1	.50	3.15	2.37	1.74	.02	.32
Cog. Level	1	.25	2.14	2.54	.55	5.02**	.49
Interaction	1	5.86**	3.48	3.77*	.24	4.01*	4.44*
Residual	85						

*p < .05

**p < .025

† Table taken from Kulm, 1977.

I think this result is important if taken only at face value. It provides ample reason to be cautious about premature extrapolation from Piaget's theory to classroom practice. The result is even more interesting when one tries to figure out what might account for the unexpected result.

An examination of the laboratory materials used in Kulm's study gives some indication of why he got his unexpected results. Appendix A shows the first laboratory activity used in Unit II and Appendix B shows the unit test.

Unit II was on numeration systems and dealt with the meaning of place value through activities which required students to express quantities in numerals to bases other than the standard base of 10. As can be seen from the exercise shown in Appendix A, the laboratory activity involved the use of physical systems as analogs to the system of numeration under consideration. In the example shown, Dienes blocks were used to represent a base 6 system of numeration.*

*The blocks consist of a "unit" which measures 1 cm x 1 cm x 1 cm, a "long" which measures 1 cm x 1 cm x 6 cm, a "flat" which measures 1 cm x 6 cm x 6 cm, and a "block" which measures 6 cm x 6 cm x 6 cm. These correspond respectively to 6^0, 6^1, 6^2, and 6^3.

Kulm describes his lecture activities as "a standard lecture-textbook presentation" and it included activities somewhat like those implied by the unit test shown in Appendix B.

An examination of Table 1 indicates that the laboratory activities may have helped the formal operational students but not the concrete operational students. Why? The answer is that the laboratory activity is valuable only if the student sees a relationship between the physical activity and the numeration system that it is intended to represent. In order to see such relationships, the student must be able to abstract from the physical activity the form of the logic that is inherent in that system and transfer that to the numerical representation of the system. This kind of mental activity is characteristic of formal operational thought but not concrete operational thought.

It is quite likely that the concrete students in the lab saw two activities; one was an activity with wooden blocks, the other was an activity with numbers. They probably saw them as unrelated. Consequently, the laboratory activity contributed little to their understanding of the ideas being taught. The formal students were able to see this relationship between numerical and physical representation, however, and the concrete referent helped them understand the idea of place value which is at the root of the activity.

The difference in achievement in the lecture section is more difficult to explain. The most plausible explanation is the one offered by Kulm. He suggests that the formal students may have been bored by the lecture approach which was basically algorithmic. They may not have practiced the homework assignments as much as the concrete students because they already understood the principle, and when they came to the test, they made more computational errors.

The point that I wish to make in regard to this study is that we cannot assume that a laboratory activity requires no more than concrete operational thought or that a particular physical experience will help a student who operates at the concrete operational level. Providing students with "concrete experience" will have no value if formal operational thought is needed in order to make sense out of the experience.

My interpretation of Kulm's experimental result grows out of experience in teaching science to concrete operational students. As a teacher I have frequently been frustrated by my efforts to make some principle or skill meaningful through use of analogies. They frequently don't work.

I must be careful here to make a distinction between analogies which are of little value in teaching concrete operational students and illustrations which have considerable value.

If one wants to teach the principle that compounds called indicators have different colors in acid and base solutions, an illustration is easily given. One simply adds an indicator to an acid and a base and perhaps pours the solutions back and forth to show the color change. There is no problem here. We are dealing with direct observation and the observation is directly related to the idea being taught.

We face a different situation when we want to teach the difference in a weak acid and a strong acid. The key idea here is that some acids are completely dissociated while others are not. There is no way to illustrate dissociation; we cannot magnify solutions of acetic acid and hydrochloric acid and invite our students to count the number of molecules that are still intact. The best that we can do is show some physical model or hypothetical picture of the system and suggest that reality is analogous to the model. We have not

illustrated what happens; we have provided an analogy to what happens. In this instance, the analogy may be sufficiently close to reality that concrete operational students accept the analogy as an illustration--that is, as a picture of the real system. If so, the analogy may be of some help but other analogies require far more extrapolation and seem to be of no value whatsoever.

In trying to get students to understand how a double pan balance operates, I have had students explore a meter stick balance and then used it as an analog of the double pan balance. Typical concrete operational students see no relationship. In teaching students to solve stoichiometric problems such as, "One mole of sodium weighs 23 g. How many moles of sodium weigh 254 g?" I often begin with an analogous problem closer to their experience; e.g., "One dozen eggs cost 82¢. How many dozen eggs cost 532¢?" Students often see no connection between the problems.

The most elaborate analogy that I have used is one in which I used nuts and bolts to represent atoms, calculated the relative weights of these "model atoms", used them to make "molecules", and had students calculate the empirical formula for samples of such "compounds" as a prelude to the same kind of activity with real compounds. Most students saw no relationship between the nuts and bolts and atoms and molecules.

I am not ready to say that concrete analogs for abstract mathematical relationships or abstract models of chemical systems cannot be used effectively to help concrete operational students but I am ready to say that I do not know how to do that consistently and I don't know anybody else who knows how to do it consistently. Until we learn how to do it, people who assume that any concrete experience will help concrete operational students are in for a rude awakening.

All of us know that students don't have trouble with all of the ideas that we teach in chemistry. However, I am not sure that we have given sufficient attention to the ideas that do cause problems and the reasons that they cause problems. It seems to me that we need some kind of taxonomy of chemical concepts that allows us to predict in advance that a student at the concrete operational level is likely to encounter difficulty. I have begun working on such a taxonomy and would like to share some of the ideas that seem to be useful at this time. (Herron, in press)

So far we have delineated three classes of concepts, those that have perceptible examples and perceptible attributes, those that have perceptible examples but no perceptible attributes, and those that have neither perceptible examples nor perceptible attributes. Concepts that have perceptible examples and perceptible attributes may be thought of as "concrete concepts" because they are easily perceived. Solid and liquid are such concepts. One has no difficulty showing numerous examples of solids or liquids. The examples are clearly perceptible. In similar fashion, one can demonstrate that solids hold their shape whereas liquids do not--the primary defining attribute of the concepts. Thus, the attributes of the concept are also perceptible. Such concepts are easily learned by direct experience using reasoning patterns characteristic of concrete operational thought.

Concepts such as element and compound present different problems. Although one has no trouble showing examples of elements or compounds--i.e., the examples are perceptible--one is hard put to show what it is about a substance that <u>makes</u> it an element or a compound; i.e., the attributes of the concept are not perceptible. Concepts such as atom and molecule go one step further. In this case both the examples and the attributes are imperceptible.

Concepts that have imperceptible examples, imperceptible attributes, or both, might be regarded as formal concepts. Such concepts cannot be learned through direct, concrete experience. It is quite likely that they cannot be totally understood without some formal operational reasoning.

We have begun to look more carefully at these hypotheses. One of my doctoral students, Luis Cantu, and I developed six lessons over concepts that ranged from very concrete to very formal. These lessons were then taught to a group of high school students who had been classified as concrete operational or formal operational on the basis of their performance on the Longeot test. (Longeot, 1962, 1965) We hypothesized that there would be no difference in what was learned by the formal and concrete operational students when they studied concrete concepts but there would be a significant difference when they studied formal concepts.

The mean score for the concrete and formal students on tests over each concept is shown in Table 3.

Table 3

Means and Mean Percents for Achievement Tests

	Concrete Concepts		
Group	MIB	Metal	Acid-Base (operational)
Concrete	$\bar{X}$ 21.20 % 85	19.33 81	15.80 66
Formal	$\bar{X}$ 23.05 % 92	20.88 87	20.08 84

	Formal Concepts			
Group	Ideal Gas (examples)	Ideal Gas (no examples)	Isomer	Acid-Base (Bronsted-Lowry)
Concrete	$\bar{X}$ 14.75 % 61	12.15 51	12.08 60	13.33 37
Formal	$\bar{X}$ 17.31 % 72	15.92 66	16.29 81	19.75 55

Although the data do not support our hypothesis overwhelmingly, we are encouraged by the data. The difference in achievement on two of the concrete concepts, MIB and metal, is less than 10%. This difference is small enough that we cannot rule out the possibility that it occurred by chance alone. The difference in achievement on the third concept, an operational concept of acid and base, is large enough that we can say that it is not due to chance. However, difficulties that occurred when this concept was taught lead us to place less faith in that result.

All of the lessons were taught during a 20 minute activity period and the test over the lesson was administered during the same period. In the lesson over acid and base (operational) the student had to test a number of solutions with litmus, check their conductivity, and see if there was a reaction with zinc which would produce hydrogen gas. The concrete operational students were less organized than the formal operational students and several of them were rushed to finish the activity. It is quite possible that the result on this lesson was due to factors other than difference in intellectual development. It is also possible that experimental aspects of the lesson required formal thought. We are not sure at this time.

What we are sure about is that the difference in achievement between concrete and formal operational students is much less when they study concrete concepts than when they study formal concepts. Isomer, ideal gas, and the Brönsted-Lowry concept of acid and base are all concepts that lack perceptible instances, perceptible attributes, or both. They are formal concepts. The difference in achievement on these formal concepts was about double the difference in achievement on the concrete concepts.

The significance of this study is that it suggests that it may be possible to use Piaget's theory to identify concepts which are likely to be difficult for concrete

operational students to learn. Knowing this, we may be able to restructure our courses so that these concepts are at least postponed until students have developed a vocabulary and some basic skills that may make these concepts more accessible.

We are, of course, anxious to learn how we can make formal concepts understandable to students. One aspect of the study that I have described touches on this question.

I have suggested that many concepts are difficult because they lack perceptible instances or perceptible attributes or both. Ideal gas is just such a concept. It is, if you will, a figment of our imagination. How can we make it real to students? One strategy is to use what I have called "pseudo-examples." We show small BB's bouncing about in some kind of random fashion; we show what happens when we apply pressure to this system of BB's; we draw illustrations of BB's that are essentially point masses and show what we think would happen when the pressure becomes very great. These are not illustrations that we are giving. They are not real examples of the behavior of an ideal gas. They are, I suppose, a kind of analogy. However, they are analogies that closely mimic the real thing. They are analogies like those often used in mathematics--a dot on a piece of paper to represent a point, a mark on a sheet of paper to represent a line, a figure made by connecting three of these "lines" to represent a triangle. These representations are <u>not</u> the same as the concept being taught but they come so close that few students ever realize that they are <u>not</u> actual examples of the concept.

In this study we first taught the concept of an ideal gas using line drawings to illustrate the behavior of an ideal gas and to contrast its behavior with that of a real gas. Concrete operational students who studied this lesson scored 61% on the test following the lesson and formal operational

students scored 72%. We then taught the same lesson to another group of students but left out the illustrations. In this case, the mean for the concrete operational students was 51% and the mean for the formal students was 66%. It should be noted that the use of pseudo-examples improved the performance of both formal and concrete operational students but the effect seems to be slightly greater for the concrete operational students. This may not always be the case. Sheehan found that when he improved instructional materials, formal operational students benefited more than concrete operational students. (Sheehan, 1970)

I believe that those of us who see Piaget's theory of intellectual development as a guide for improvement of science instruction are looking in the right direction. However, I believe that there is a substantial gap between what we are able to learn from that theory and what we must know in order to apply it in the classroom. I believe that there is some danger that individuals who have not thought carefully through the implications of the theory may rush into curriculum changes that will later prove to be futile and, in the process, become disillusioned about what might be done with more careful investigation and development.

I would like to encourage more people to engage in small, carefully planned investigations that will lead to a better understanding of what chemistry concepts cause problems and why; what strategies will help us to teach these concepts and how; what thinking students are using as they approach typical chemical problems and how it can be improved. If and when we begin to accumulate information of this sort, we will be able to plan our curricula on the basis of something other than subjective judgment and we may approach the happy day that all students can understand the science that we want to teach.

My suggestion then, is not actually a suggestion for inaction. Rather, it is a suggestion that the actions needed at this time are ones that will provide more detailed information about how we can use knowledge concerning intellectual development to arrive at empirically proven generalizations concerning instruction. Then, and only then, will we be close to solving the frustrating problem of teaching chemistry to students who are now unable to learn it.

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Unit II Numeration Systems

Lab II - 1

Objectives:

Write expanded numerals for
a. decimal base numerals
b. non-decimal base numerals

Materials: Multibase blocks: base 6, 10

Procedures:

A. For the following explorations, use base 6 wood.

1. Determine the number of:
   a. Units required to form one long, _____.
   b. Units required to form one flat, _____; longs required to form one flat, _____.
   c. Units required to form one block, _____; longs required to form one block, _____.
2. Count out 17 units. By means of trading (units for longs, longs for flats, etc.) express 17 in terms of the fewest number of pieces of wood. How many blocks, flats, longs and units did you use? _____ blocks, _____ flats, _____ longs, _____ units.
3. Follow the same procedure as in Question 2 for:
   a. 24 units = _____ blocks, _____ flats, _____ longs, _____ units.
   b. 57 units = _____ blocks, _____ flats, _____ longs, _____ units.
   c. 143 units = _____ blocks, _____ flats, _____ longs, _____ units.
   d. 746 units = _____ blocks, _____ flats, _____ longs, _____ units.
4. Give a general rule for trading units for longs, longs for flats, or flats for blocks, in base 6. _____
5. What base 6 numbers can be expressed in terms of *only*:
   a. Units? _____
   b. Longs? _____
   c. Flats? _____
   d. Blocks? _____

6. What base 6 numbers can be expressed in terms of:
   a. Longs and units only (at least one of each)? _____
   b. Flats and longs only? _____
   c. Flats, longs and units? _____
   d. Blocks and units? _____
   e. Blocks and longs? _____
   f. Blocks, longs and units? _____
   g. Blocks and flats? _____
   h. Blocks, flats and units? _____
   i. Blocks, flats and longs? _____
   j. Blocks, flats, longs and units? _____

7. What is the largest base 6 number which can be expressed in terms of units only (that is, before trading must occur)? _____ Longs only? _____ Flats only? _____ Blocks only? _____

8. Answer Question 7 for the smallest base 6 number:
   Units only? _____ Longs? _____ Flats? _____
   Blocks? _____

B. Using base 10 wood, answer Questions 1-8.

C. Generalize your answer to Questions 1, 4, 5, 6, 7 and 8 for any base b wood.

Appendix B

MATH 130

Unit II Test

Choose the one best answer to each of the following.

1. Which item represents 520143_6 in expanded notation?
   (a) $5x10^5 + 2x10^4 + 0x10^3 + 1x10^2 + 4x10^1 + 3x10^0$
   (b) $5x6^6 + 2x6^5 + 0x6^4 + 1x6^3 + 4x6^2 + 3x6^1$
   (c) $5x6^5 + 2x6^4 + 0x6^3 + 1x6^2 + 4x6^1 + 3x6^0$
   (d) $5x10^6 + 2x10^5 + 0x10^4 + 1x10^3 + 4x10^2 + 3x10^1$
   (e) None of the above

2. Which item represents $3x10^3 + 2x10^2 + 8x10^1 + 5x10^0 + 2x10^{-1} + 4x10^{-2}$ in standard notation?
   (a) 3285.24
   (b) 32850.24
   (c) 328.524
   (d) 3285.024
   (e) None of the above

3. Which of the following is equal to 142_5?
   (a) 1112_3
   (b) 66_7
   (c) 232_4
   (d) 55_8
   (e) 115_6

4. Choose the item which represents 123_{10} as a base seven (7) numeral.
   (a) 234_7
   (b) 324_7
   (c) 221_7
   (d) 432_7
   (e) 232_7

5. Choose the item which represents 248_{10} as a base four (4) numeral.
   (a) 332_4
   (b) 3123_4
   (c) 3320_4
   (d) 233_4
   (e) None of the above

6. Choose the item which is the correct answer for the multiplication problem in base 5.
   (a) 1131_5
   (b) 2030_5
   (c) 1031_5
   (d) 2131_5
   (e) None of the above

$$\begin{array}{r} 342_5 \\ \times\ 3_5 \\ \hline \end{array}$$

7. Choose the item which is the correct answer for the addition problem in base 7.
   (a) 2151_7
   (b) 1151_7
   (c) 1121_7
   (d) 1051_7
   (e) None of the above

$$\begin{array}{r} 256_7 \\ +562_7 \\ \hline \end{array}$$

8. Choose the item which is the correct answer for the subtraction problem in base 6.
   (a) 435_6
   (b) 423_6
   (c) 444_6
   (d) 434_6
   (e) None of the above

$$\begin{array}{r} 512_6 \\ -34_6 \\ \hline \end{array}$$

9. Construct a base six (6) addition table.

10. Construct a base three (3) multiplication table.